

10/594009

04081-UN

1AP9 Rec'd PCT/PTO 25 SEP 2006

SPECIFICATION

TITLE OF THE INVENTION

5 PHASE-SHIFTING CIRCUIT AND MULTIBIT PHASE SHIFTER

TECHNICAL FIELD

【0001】

The present invention relates to a miniature, low-loss
10 phase-shifting circuit and multibit phase shifter.

BACKGROUND ART

【0002】

FIG. 28 is a circuit diagram showing a configuration of
15 a conventional phase-shifting circuit disclosed in C. F.
Campbell and S. A. Brown, "A Compact 5-Bit Phase Shifter MMIC
for K-Band Satellite Communication Systems", IEEE IMS2000
Proceedings. In FIG. 28, the phase-shifting circuit includes
a high frequency signal input terminal 101, high frequency signal
20 output terminal 102, first field-effect transistor (abbreviated
to "FET" from now on) 103, second FET 104, first inductor 105,
second inductor 106, third inductor 107, capacitor 108 and ground
109.

In the circuit, the field-effect transistor (abbreviated
25 to "FET" from now on) 103 operates as a switch for switching
between an ON state and OFF state. When a voltage equipotential
to a drain voltage and source voltage is applied to a gate
terminal, the FET 103 enters into an ON state, and exhibits a
resistive property (called "ON resistance" from now on). On the
30 other hand, when a voltage equal to or less than a pinch-off

voltage is applied to the gate terminal, the FET 103 enters into an OFF state, and exhibits a capacitive property (called "OFF capacitance" from now on). The other FET 104 operates in the same manner as the FET 103.

5 **【0003】**

FIG. 29 is a circuit diagram showing an equivalent circuit when bringing the FET 103 into the OFF state and FET 104 into the ON state in the phase-shifting circuit of FIG. 28. Here, the reference numeral 110 designates a combined capacitance of the OFF capacitance of the FET 103 and the capacitor 108, and 111 designates the ON resistance of the FET 104. In this case, the equivalent circuit shown in FIG. 29 can be considered as a high-pass filter (abbreviated to "HPF" from now on) composed of the combined capacitance 110, inductor 105 and inductor 106. A high frequency signal input to the high frequency signal input terminal 101 undergoes a phase lead through the HPF, and is output from the high frequency signal output terminal 102.

【0004】

FIG. 30 is a circuit diagram showing an equivalent circuit when bringing the FET 103 into ON state and FET 104 into OFF state in the phase-shifting circuit of FIG. 28. Here, the reference numeral 112 designates the ON resistance of the first FET 103, and 113 designates the OFF capacitance of the second FET 104. The parallel circuit composed of the inductor 107 and OFF capacitance 113 is set in such a manner as to produce a parallel resonance state at a desired frequency f_0 . In this case, the equivalent circuit shown in FIG. 30 can be considered as a bandpass filter (abbreviated to "BPF" from now on) that passes a high frequency signal near the frequency f_0 under the assumption that the reactance the inductor 105 and inductor 106 exhibit

is sufficiently greater than the ON resistance 112. The high frequency signal input to the high frequency signal input terminal 101 is output from the high frequency signal output terminal 102 with nearly zero phase variation through the BPF.

5 **【0005】**

Here, the difference between the phase lead caused by the HPF and the phase variation caused by the BPF is referred to as a necessary phase shift amount. The high frequency signal input through the high frequency signal input terminal 101
10 obtains the desired phase shift amount by switching the ON/OFF state of the FET 103 and FET 104, and is output from the high frequency signal output terminal 102.

As described above, since the conventional phase-shifting circuit must set the cutoff frequency of the HPF at a frequency
15 lower than the desired frequency bandwidth, the size of the circuit increases as the frequency becomes lower. In addition, since the cutoff frequency of the HPF must be lowered with the reduction in the phase shift amount, the circuit has a problem of increasing its size.

20 **【0006】**

The present invention is implemented to solve the foregoing problems. Therefore it is an object of the present invention to provide a phase-shifting circuit and multibit phase shifter with characteristics of a small size and low loss.

25

DISCLOSURE OF THE INVENTION

【0007】

A phase-shifting circuit in accordance with the present invention includes: an input terminal of a high frequency signal;
30 an output terminal of the high frequency signal; a first parallel

circuit which is connected across the input terminal and the output terminal, which is composed of a first inductor and a first switching element that exhibits a through state or resistive property in an ON state and a capacitive property in an OFF state, and which produces parallel resonance at a prescribed frequency when the first switching element is in the OFF state; a series circuit which is connected in parallel with the first parallel circuit, and which is composed of a second inductor and a third inductor that have a reactance sufficiently larger than a resistance of the first switching element in the ON state; a capacitor having its first terminal connected to a point of connection of the second inductor and the third inductor; a second parallel circuit which is connected across a second terminal of the capacitor and a ground, which is composed of a fourth inductor and a second switching element that exhibits a through state or resistive property in an ON state and a capacitive property in an OFF state, and which produces parallel resonance at a prescribed frequency when the second switching element is in the OFF state; and applying means of control signals for establishing a first operation mode and a second operation mode by switching between them, the first operation mode setting the first switching element at the ON state and the second switching element at the OFF state, and the second operation mode setting the first switching element at the OFF state and the second switching element at the ON state.

【0008】

This makes it possible to form a bandpass filter circuit and low-pass filter circuit by switching, and to vary the pass phase of the high frequency signal input, thereby being able to obtain a desired phase shift amount at a low loss. In addition,

since the phase-shifting circuit employs the low-pass filter, it can reduce the size of the inductors as compared with a conventional example that employs a high-pass filter, thereby being able to miniaturize itself. Furthermore, since the phase-shifting circuit can be composed of the two switching elements, four inductors, a single capacitor, and a single through hole, it offers an advantage of being able to miniaturize the circuit.

10 BRIEF DESCRIPTION OF THE DRAWINGS

【0009】

FIG. 1 is a circuit diagram showing a configuration of the phase-shifting circuit of an embodiment 1 in accordance with the present invention;

15 FIG. 2 is a circuit diagram showing an equivalent circuit of the phase-shifting circuit of the embodiment 1 in accordance with the present invention;

FIG. 3 is a circuit diagram showing an equivalent circuit when the phase-shifting circuit of the embodiment 1 in accordance with the present invention operates as a bandpass filter circuit;

FIG. 4 is a circuit diagram showing an equivalent circuit when the phase-shifting circuit of the embodiment 1 in accordance with the present invention operates as a low-pass filter circuit;

25 FIG. 5 is a circuit diagram showing a configuration of the phase-shifting circuit of an embodiment 2 in accordance with the present invention;

FIG. 6 is a circuit diagram showing an equivalent circuit when the phase-shifting circuit of the embodiment 2 in accordance with the present invention operates as a bandpass filter circuit;

30 FIG. 7 is a circuit diagram showing an equivalent circuit

when the phase-shifting circuit of the embodiment 2 in accordance with the present invention operates as a low-pass filter circuit;

FIG. 8 is a circuit diagram showing a configuration of the phase-shifting circuit of an embodiment 3 in accordance with the present invention;

FIG. 9 is a circuit diagram showing an equivalent circuit when the phase-shifting circuit of the embodiment 3 in accordance with the present invention operates as a bandpass filter circuit;

FIG. 10 is a circuit diagram showing an equivalent circuit when the phase-shifting circuit of the embodiment 3 in accordance with the present invention operates as a low-pass filter circuit;

FIG. 11 is a circuit diagram showing a configuration of the phase-shifting circuit of an embodiment 4 in accordance with the present invention;

FIG. 12 is a plan view showing a structure of the phase-shifting circuit formed on a substrate of an embodiment 5 in accordance with the present invention;

FIG. 13 is an exploded view showing a detailed structure of a through/open switching element of the embodiment 5 in accordance with the present invention;

FIG. 14 is a sectional view showing an open-state structure of the through/open switching element of the embodiment 5 in accordance with the present invention;

FIG. 15 is a sectional view showing a through-state structure of the through/open switching element of the embodiment 5 in accordance with the present invention;

FIG. 16 is an exploded view showing a detailed structure of a through/shunt capacitance switching element of the embodiment 5 in accordance with the present invention;

FIG. 17 is a sectional view showing a through-state

structure of the through/shunt capacitance switching element of the embodiment 5 in accordance with the present invention;

FIG. 18 is a sectional view showing a capacitance state of the through/shunt capacitance switching element of the embodiment 5 in accordance with the present invention;

FIG. 19 is a circuit diagram showing an equivalent circuit of the phase-shifting circuit of the embodiment 5 in accordance with the present invention;

FIGs. 20(a) and 20(b) are circuit diagrams showing equivalent circuits of a through circuit and low-pass filter circuit of the embodiment 5 in accordance with the present invention;

FIG. 21 is a plan view showing a detailed structure of a through/open switching element used for the phase-shifting circuit of an embodiment 6 in accordance with the present invention;

FIG. 22 is a sectional view showing an open-state structure of the through/open switching element of the embodiment 6 in accordance with the present invention;

FIG. 23 is a sectional view showing a through-state structure of the through/open switching element of the embodiment 6 in accordance with the present invention;

FIG. 24 is a plan view showing a detailed structure of a through/shunt capacitance switching element of the embodiment 6 in accordance with the present invention;

FIG. 25 is a sectional view showing a through-state structure of the through/shunt capacitance switching element of the embodiment 6 in accordance with the present invention;

FIG. 26 is a sectional view showing a capacitance state of the through/shunt capacitance switching element of the

embodiment 6 in accordance with the present invention;

FIG. 27 is a block diagram showing a configuration of a multibit phase shifter of an embodiment 7 in accordance with the present invention;

5 FIG. 28 is a circuit diagram showing a configuration of a conventional phase-shifting circuit;

FIG. 29 is a circuit diagram showing an equivalent circuit when the conventional phase-shifting circuit operates as a high-pass filter; and

10 FIG. 30 is a circuit diagram showing an equivalent circuit when the conventional phase-shifting circuit operates as a bandpass filter.

BEST MODE FOR CARRYING OUT THE INVENTION

15 【0010】

The best mode for carrying out the invention will now be described with reference to the accompanying drawings to explain the present invention in more detail.

EMBODIMENT 1

20 FIG. 1 is a circuit diagram showing a configuration of the phase-shifting circuit of an embodiment 1 in accordance with the present invention.

In FIG. 1, the phase-shifting circuit is formed monolithically on a semiconductor substrate 14. It is configured in such a manner that a parallel circuit (first parallel circuit) composed of an FET (first switching element) 3a and a spiral inductor (first inductor) 4 is connected across a high frequency signal input terminal 1 and an output terminal 2, and that the FET 3a has its gate supplied with a first control signal from an input terminal 12 via a resistor 9. In addition,

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a series circuit composed of a spiral inductor (second inductor) 5 and a spiral inductor (third inductor) 6 is also connected in parallel with the parallel circuit. The point of connection between the spiral inductor 5 and spiral inductor 6 is connected to a first terminal of an MIM capacitor 8. Between a second terminal of the MIM capacitor 8 and a through hole (ground) 11, a parallel circuit (second parallel circuit) composed of the FET (second switching element) 3b and spiral inductor 7 is connected. It is further configured in such a manner that the FET 3b has its gate supplied with a second control signal from an input terminal 13 via a resistor 10.

【0011】

FIG. 2 is a circuit diagram showing an equivalent circuit of the phase-shifting circuit of FIG. 1. Comparing FIG. 2 with FIG. 1, an inductor 15 corresponds to the spiral inductor 4, an inductor 16 corresponds to the spiral inductor 5, an inductor 17 corresponds to the spiral inductor 6, and an inductor 18 corresponds to the spiral inductor 7. A capacitor 19 corresponds to the MIM capacitor 8, and a ground 20 corresponds to the through hole 11.

【0012】

The FET 3a and FET 3b operate as a switch for switching the ON/OFF state in response to the first control signal and second control signal, respectively. The FET 3a enters into the ON state when a voltage equipotential to a drain voltage and source voltage is applied to the gate terminal as the first control signal, and exhibits a resistive property (called "ON resistance" from now on). On the other hand, when a voltage equal to or less than the pinch-off voltage is applied to the gate terminal, the FET 3a enters into the OFF state, and exhibits

a capacitive property (called "OFF capacitance" from now on). The FET 3b operates in the same manner in response to the second control signal.

【0013】

5 Next, the operation of the phase-shifting circuit of the embodiment 1 will be described with reference to the equivalent circuit of FIG. 2.

When the control signal sets the FET 3a at the ON state and the FET 3b at the OFF state, the equivalent circuit of FIG. 2 is considered to become the equivalent circuit as shown in FIG. 3. In this operation mode, since the FET 3a is in the ON state, it is represented as an ON resistance 21, and since the FET 3b is in the OFF state, it is represented as an OFF capacitance 22. Here, the parallel circuit composed of the inductor 18 and OFF capacitance 22 is set in such a manner as to bring about a parallel resonance (open) state at a prescribed frequency f_0 . Since the reactance caused by the inductor 16 and inductor 17 is sufficiently larger than the ON resistance 21 of the FET 3a, the circuit of FIG. 3 can be considered as a bandpass filter circuit with a passband near the prescribed frequency f_0 . When the ON resistance 21 is sufficiently small, it brings about little phase variation. Accordingly, the high frequency signal input to the input terminal 1 at the prescribed frequency f_0 is output from the output terminal 2 without the phase variation.

25 【0014】

When the control signal sets the FET 3a at the OFF state, and the FET 3b at the ON state, the equivalent circuit of FIG. 2 is considered to become the equivalent circuit as shown in FIG. 4. In this operation mode, since the FET 3a is in the OFF state, it is represented as an OFF capacitance 23, and since

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the FET 3b is in the ON state, it is represented as an ON resistance 24. Here, when the reactance of the inductor 18 is set sufficiently larger than the ON resistance 24 of the FET 3b, the parallel circuit composed of the ON resistance 24 and inductor 18 can be considered a circuit consisting of only the ON resistance 24. In addition, the parallel circuit composed of the inductor 15 and the OFF capacitance 23 of the FET 3a is set in such a manner as to bring about a parallel resonance (open) state at the prescribed frequency f_0 . In this case, the circuit as shown in FIG. 4 can be considered a low-pass filter circuit composed of the inductors 16 and 17 and the capacitor 19, and setting its circuit constants appropriately enables the low-pass filter circuit to establish matching, resulting in a low reflection loss. Accordingly, the high frequency signal input to the input terminal 1 is output from the output terminal 2 with a phase lag caused by the low-pass filter circuit.

【0015】

As described above, the phase-shifting circuit of the present embodiment 1 can switch between the bandpass filter circuit and low-pass filter circuit by setting the operation mode through the ON/OFF switching of the FET 3a and FET 3b, thereby being able to vary the pass phase of the input high frequency signal. In other words, a desired phase shift amount can be achieved by the variation in the pass phase. Thus, the phase-shifting circuit is basically configured with two FETs, four inductors, a single capacitor, and a single through hole, thereby being able to miniaturize the circuit.

【0016】

In the foregoing conventional phase-shifting circuit, the cutoff frequency of the high-pass filter must be placed lower

than the desired central frequency. On the other hand, since the cutoff frequency of the low-pass filter circuit is higher than the desired central frequency, the present embodiment can make the inductance and capacitance smaller than those of the conventional example can, thereby being able to miniaturize the circuit.

【0017】

Although the phase-shifting circuits from the embodiment 1 to embodiment 4 in accordance with the present invention are described by way of examples that use the FETs as a switching element, this is not essential. Other elements can be used as long as they have a switching function of switching between the ON/OFF states. In addition, although these phase-shifting circuits are monolithically built on the semiconductor substrate 14, they can be configured by placing the passive components on a dielectric substrate and active components on a semiconductor substrate, and by electrically connecting the two substrates via metal wires or golden bumps.

20 【0018】

EMBODIMENT 2

FIG. 5 is a circuit diagram showing a configuration of the phase-shifting circuit of the embodiment 2 in accordance with the present invention. In FIG. 5, the same or like portions to those of FIG. 2 are designated by the same reference numerals, and duplicate explanation will be omitted basically. The configuration of the phase-shifting circuit includes an FET (third switching element) 25 in place of the capacitor 19 of FIG. 2.

30 The FET 25, which operates as a switch for switching the

ON/OFF state, carries out the operation in the same manner as the FET 3a and FET 3b in response to the control signal.

【0019】

Next, the operation will be described.

5 When the control signal sets the FET 3a at the ON state, the FET 3b at the OFF state and the FET 25 at the ON state, the phase-shifting circuit of FIG. 5 is considered to become the equivalent circuit as shown in FIG. 6. In FIG. 6, the same or like components to those of FIG. 3 are designated by the same
10 reference numerals. Here, the FET 25 in the ON state is represented as an ON resistance 26.

 In the circuit of FIG. 6, the parallel circuit composed of the inductor 18 and OFF capacitance 22 is set in such a manner as to bring about a parallel resonance (open) state at the
15 prescribed frequency f_0 as in the circuit of FIG. 3. Since the reactance caused by the inductor 16 and inductor 17 is sufficiently larger than the ON resistance 21, the phase-shifting circuit can be considered as a bandpass filter circuit with a passband near the prescribed frequency f_0 in this
20 operation mode. When the ON resistance 21 is sufficiently small, it brings about little phase variation. Accordingly, the high frequency signal input to the input terminal 1 at the prescribed frequency f_0 is output from the output terminal 2 without the phase variation.

25 【0020】

 In the circuit of the foregoing embodiment 1 as shown in FIG. 3, the series circuit mainly composed of the inductor 16, capacitor 19 and inductor 18 brings about a series resonance state at a frequency lower than the prescribed frequency f_0 ,
30 which can affect the characteristics of the phase-shifting

circuit near f_0 . In contrast with this, the circuit shown in FIG. 6 prevents the series resonance by replacing the capacitor 19 by the ON resistance 26. This can eliminate the effect on the characteristics of the phase-shifting circuit near f_0 ,
5 thereby being able to offer good characteristics.

【0021】

In contrast, when the control signal sets the FET 3a at the OFF state, the FET 3b at the ON state and the FET 25 at the OFF state, the phase-shifting circuit of FIG. 5 can be considered
10 the equivalent circuit as shown in FIG. 7. In FIG. 7, the same or like components to those of FIG. 4 are designated by the same reference numerals. Here, the FET 25 in the OFF state is represented as an OFF capacitance 27.

In the circuit of FIG. 7, when the reactance caused by the
15 inductor 18 is set sufficiently larger than the ON resistance 24 as in the circuit of the foregoing embodiment 1 of FIG. 4, the parallel circuit composed of the ON resistance 24 and inductor 18 can be considered as a circuit consisting of only the ON resistance 24. In addition, the parallel circuit composed
20 of the inductor 15 and OFF capacitance 23 is set in such a manner as to bring about the parallel resonance (open) state at a desired frequency f_0 . In this operation mode, the phase-shifting circuit can be considered a low-pass filter circuit composed
25 of the inductors 16 and 17 and the OFF capacitance 27, and setting its circuit constants appropriately enables the low-pass filter circuit to establish matching, resulting in a low reflection loss. Accordingly, the high frequency signal input to the input terminal 1 is output from the output terminal 2 with a phase lag caused by the low-pass filter circuit.

30 【0022】

As described above, the phase-shifting circuit of the present embodiment 2 can switch between the bandpass filter circuit and low-pass filter circuit by setting the operation mode through the ON/OFF switching of the FET 3a, FET 3b and FET 25, thereby being able to vary the pass phase of the high frequency signal input to the input terminal 1. Accordingly, it offers an advantage similar to that of the phase-shifting circuit of the foregoing embodiment 1. In addition, since it does not bring about the series resonance at the frequency lower than the prescribed frequency f_0 in the state of the bandpass filter circuit, it offers an advantage of eliminating the adverse effect on the characteristics of the phase-shifting circuit near f_0 .

15 【0023】

EMBODIMENT 3

FIG. 8 is a circuit diagram showing a configuration of the phase-shifting circuit of an embodiment 3 in accordance with the present invention. In FIG. 8, the same or like portions to those of FIG. 2 are designated by the same reference numerals, and duplicate explanation will be omitted basically. The configuration of the phase-shifting circuit replaces the parallel circuit composed of the inductor 18 and FET 3b of FIG. 2 by only the FET 3b (second switching element).

25 【0024】

Next, the operation will be described.

When the control signal sets the FET 3a at the ON state and the FET 3b at the OFF state, the phase-shifting circuit of FIG. 8 can be considered to have an equivalent circuit as shown in FIG. 9. In FIG. 9, the same or like components to those of

FIG. 3 are designated by the same reference numerals.

In the circuit of FIG. 9, the combined capacitance of the capacitor 19 and OFF capacitance 22 is set in such a manner to become nearly an open state. Here, since the reactance caused by the inductor 16 and inductor 17 are set sufficiently larger than the ON resistance 21, the circuit can be considered as a through circuit via the ON resistance 21 in this operation mode. When the ON resistance 21 is sufficiently small, it brings about little phase variation. Accordingly, the high frequency signal input to the input terminal 1 is output from the high frequency signal output terminal 2 without causing a phase variation.

【0025】

When the FET 3a is set at the OFF state, and the FET 3b is set at the ON state, the circuit of FIG. 8 can be considered to have an equivalent circuit as shown in FIG. 10. In FIG. 10, the same or like components to those of FIG. 4 are designated by the same reference numerals.

In the circuit of FIG. 10, the parallel circuit composed of the inductor 15 and OFF capacitance 23 is set in such a manner as to being about the parallel resonance (open) state at the prescribed frequency f_0 as in FIG. 4. Accordingly, the circuit can be considered a low-pass filter circuit composed of the inductors 16 and 17 and capacitor 19 in this operation mode. Appropriately setting the circuit constants can establish the matching, thereby being able to eliminate the reflection loss. Accordingly, the high frequency signal input to the input terminal 1 is output from the output terminal 2 with the phase lag brought about by the low-pass filter circuit.

A similar effect can be achieved by replacing the parallel circuit composed of the inductor 18 and FET 3b in the foregoing

embodiment 2 of FIG. 5 by only the FET 3b.

【0026】

As described above, the phase-shifting circuit of the present embodiment 3 can switch between the through circuit and
5 low-pass filter circuit by setting the operation mode through the ON/OFF switching of the FET 3a and FET 3b, thereby being able to vary the pass phase of the input high frequency signal input to the input terminal 1. Thus, the present embodiment 3 can offer advantages similar to those of the phase-shifting
10 circuit of the foregoing embodiment 1. In addition, since it can remove one inductor from the phase-shifting circuit of the embodiment 1, it can further miniaturize the circuit.

【0027】

15 EMBODIMENT 4

FIG. 11 is a circuit diagram showing a configuration of the phase-shifting circuit of an embodiment 4 in accordance with the present invention. In FIG. 11, the same or like portions to those of FIG. 2 are designated by the same reference numerals,
20 and duplicate explanation will be omitted basically. The configuration of the phase-shifting circuit includes FETs 3a' and 3b' corresponding to the FETs 3a and 3b of FIG. 2, and capacitors 28 and 29 connected in parallel to them.

【0028】

25 When the FET 3a' is set at the ON state and the FET 3b' is set at the OFF state, the phase-shifting circuit of FIG. 11 has the equivalent circuit as shown in FIG. 3 and operates in the same manner. Here, consider implementing the same capacitance as the OFF capacitance 22 of the FET 3b in the
30 foregoing embodiment 1. In the case of FIG. 11 which has the

additional capacitor 29, the OFF capacitance of the FET 3b' can be made smaller than that of the FET 3b. Thus, the size of the FET 3b' can be made smaller than that of the FET 3b.

【0029】

5 When the FET 3a' is set at the OFF state and the FET 3b' is set at the ON state, the phase-shifting circuit of FIG. 11 has the equivalent circuit as shown in FIG. 4 and operates in the same manner. Here, consider implementing the same capacitance as the OFF capacitance 23 of the FET 3a of the
10 foregoing embodiment 1. In the case of FIG. 11 which has the additional capacitor 28, the OFF capacitance of the FET 3a' can be made smaller than that of the FET 3a. Thus, the size of the FET 3a' can be made smaller than that of the FET 3a.

【0030】

15 As described above, the phase-shifting circuit of the present embodiment 4 can offer the same advantages as the embodiment 1. In addition, the present embodiment 4 can reduce the size of the FETs used as the switching elements as compared with the phase-shifting circuit of the embodiment 1, thereby
20 being able to miniaturize the phase-shifting circuit.

【0031】

EMBODIMENT 5

FIG. 12 is a plan view showing a configuration of the
25 phase-shifting circuit of the embodiment 5 in accordance with the present invention, which is formed on a substrate and has a coplanar line structure.

In FIG. 12, a cavity 36 is formed in a substrate 32 by digging down into the substrate from its one side using micromachining
30 technology. A dielectric supporting film 37 is supported at

edges of the cavity 36 in such a manner as to extend across the hollow via an air layer. On the dielectric supporting film 37, two meander lines 35a and 35b are formed at some distance away from each other. Between the undersurface of the cavity 36 and the dielectric supporting film 37, spacing from several microns to several tens of microns are provided. The undersurface of the cavity 36 may be coated with a metal or not coated. On the substrate 32, a through/open switching element (portion enclosed by broken lines) 33 and a through/shunt capacitance switching element (portion enclosed by broken lines) 34 are formed on both sides of the cavity 36.

[0032]

FIG. 13 is an exploded view showing a detailed structure of the through/open switching element 33 shown in FIG. 12.

The substrate 38 (which is identical to the substrate 32 of FIG. 12) has a cavity 39 formed by digging down into the substrate from its one side using the micromachining technology. A contact metal 41 is formed at the center of the undersurface of the cavity 39. In addition, a control electrode 40 is formed around the contact metal 41 on the undersurface of the cavity 39. The control electrode 40 has a tongue extending upward of the substrate 38 for supplying a control voltage. The dielectric supporting film 42 is supported by the substrate 38 at a pair of edges of the cavity 39 in the location in which the dielectric supporting film 42 faces the contact metal 41 and control electrode 40, and is normally located over the hollow via the air layer of the cavity 39. The dielectric supporting film 42 has a pair of through holes 43a and 43b at the location facing to the contact metal 41. A high frequency signal transmission line 44a and high frequency signal transmission line 44b are

placed on the surface of the dielectric supporting film with a spacing between them. They have conductive projections (see FIG. 14 which will be described later) facing to the contact metal 41 at the back of the dielectric supporting film through
5 the pair of through holes 43a and 43b.

【0033】

The high frequency signal transmission lines 44a and 44b and ground metals 45a and 45b form coplanar lines with the spacing at the center. The dielectric supporting film 42 having the
10 coplanar lines normally extends across the hollow, and the cavity 39 at that case has the spacing from several microns to several tens of microns between its undersurface and the dielectric supporting film 42.

【0034】

15 Next, the operation of the through/open switching element 33 will be described.

When the control electrode 40 is not supplied with the control voltage, the structure of the through/open switching element 33 corresponding to the section taken along the line
20 A-A' of FIG. 12 has a sectional view as shown in FIG. 14. This operation mode brings about the open state because the two high frequency signal transmission lines 44a and 44b are separated from each other, and no other conductor lies between them.

On the other hand, when the control electrode 40 is supplied
25 with the control voltage, the structure of the through/open switching element 33 corresponding to the section taken along the line A-A' of FIG. 12 has a sectional view as shown in FIG. 15. In this operation mode, the dielectric supporting film 42 undergoes displacement toward the undersurface of the cavity
30 39 because of the electrostatic attraction between the control

electrode 40 and the ground metals 45a and 45b. In this case, since the conductive projections protruding through the through holes 43a and 43b make contact with the contact metal 41, the pair of high frequency signal transmission lines 44a and 44b are brought into conduction, forming a through state.

5 **【0035】**

FIG. 16 is an exploded view showing a detailed configuration of the through/shunt capacitance switching element 34 shown in FIG. 12. In FIG. 16, the same or like components to those of FIG. 13 are designated by the same reference numerals. The through/shunt capacitance switching element 34 has a cavity 46 which is formed by digging down into the substrate 38 (which is identical to the substrate 32 of FIG. 12) from its one side using the micromachining technology. On the undersurface of the cavity 46, a beltlike ground metal (first ground metal) 48 is formed. On the undersurface of the cavity 46, a control electrode 47 is formed on both sides of the ground metal 48. The control electrode 47 and ground metal 48 have portions extending from the undersurface of the cavity 46 up to the substrate 38.

20 **【0036】**

A dielectric supporting film 49 is supported by the substrate 38 at the edges of the cavity 46 in the location facing to the ground metal 48 and control electrode 47 (see FIG. 17 which will be described later), and is normally located over the hollow via the air layer of the cavity 46. The dielectric supporting film 49 has the spacing from several microns to several tens of microns between it and the undersurface of the cavity 46. In addition, the dielectric supporting film 49 is located with facing to the ground metal 48 and control electrode

47. On the dielectric supporting film 49, a high frequency signal transmission line 50 is formed in the location facing to the ground metal 48. In addition, on the dielectric supporting film 49, ground metals (second ground metal) 51a and 51b are formed in locations facing to the control electrode 47. The high frequency signal transmission line 50, ground metals 48, 51a and 51b constitute grounded coplanar lines.

【0037】

Next, the operation of the through/shunt capacitance switching element 34 will be described.

When the control electrode 47 is not supplied with the control voltage, the structure of the through/shunt capacitance switching element 34 corresponding to the section taken along the line B-B' of FIG. 12 has a sectional view as shown in FIG. 17. In this operation mode, the high frequency signal is transmitted through the grounded coplanar lines. In other words, the through/shunt capacitance switching element 34 forms the through state.

On the other hand, when the second control electrode 47 is supplied with the control voltage, the structure of the through/shunt capacitance switching element 34 corresponding to the section taken along the line B-B' of FIG. 12 has a sectional view as shown in FIG. 18. In this operation mode, the dielectric supporting film 49 undergoes displacement toward the undersurface of the cavity 46 because of the electrostatic attraction between the ground metals 51a and 51b and the control electrode 47. As a result, the dielectric supporting film 49 makes contact with the ground metal 48, and the high frequency signal transmission line 50 and the ground metal 48 come closer to each other via the dielectric supporting film 49. Accordingly,

the high frequency signal transmission line 50 has a capacitance with respect to the ground. Thus, the through/shunt capacitance switching element 34 forms a state having a capacitance against the ground.

5 **【0038】**

Next, the operation of the phase-shifting circuit as shown in FIG. 12 will be described. FIG. 19 is a circuit diagram showing the phase-shifting circuit of FIG. 12 equivalently.

10 In FIG. 19, the through/open switching element 33, which sets the transmission line at the through state or open state by the control voltage E1, is connected across the input terminal 52 (corresponding to the high frequency signal input terminal 30) of the high frequency signal and an output terminal 53 (corresponding to the high frequency signal output terminal 31).

15 In addition, an inductor 54a (corresponding to the meander line 35a) has its first terminal connected to the input terminal 52, and an inductor 54b (corresponding to the meander line 35b) has its first terminal connected to the output terminal 53. The inductor 54a and inductor 54b have their second terminals

20 connected to the through/shunt capacitance switching element 34 which sets the transmission line at the through state or capacitance state by the control voltage E2. A capacitor 55 represents a capacitance of the through/shunt capacitance switching element 34 against the ground when it is in the shunt

25 capacitance state.

【0039】

The through/open switching element 33 is switched to the through state by applying the control voltage E1 to the control electrode 40 (see FIG. 15), and at the same time the through/shunt

30 capacitance switching element 34 is set at the through state

by not applying the control voltage E2 to the control electrode 47 (equipotential to the ground) (see FIG. 17). In this case, the phase-shifting circuit of FIG. 19 (or of FIG. 12) forms the equivalent circuit as shown in FIG. 20(a). In FIG. 20(a), such
 5 a circuit is configured in which a series circuit composed of the two inductors 54a and 54b is connected across the input terminal 52 and output terminal 53, and the input terminal 52 is directly connected to the output terminal 53.

If the reactance caused by the inductors 54a and 54b is
 10 large enough, the circuit of FIG. 20(a) in this operation mode can be considered as a through circuit. Accordingly, the high frequency signal input through the input terminal 52 is output from the output terminal 53 without bringing about the phase variation. In this case, the through circuit has no reflection
 15 loss because it can establish matching at all the frequencies.

【0040】

Next, the through/open switching element 33 is made an open state by not applying the control voltage E1 to the control electrode 40 (equipotential to the ground) (see FIG. 14), and
 20 at the same time the through/shunt capacitance switching element 34 is set at a shunt capacitance state by applying the control voltage E2 to the control electrode 47 (see FIG. 18). In this case, the phase-shifting circuit of FIG. 19 (or of FIG. 12) forms the equivalent circuit as shown in FIG. 20(b). In FIG. 20(b),
 25 the same or like components to those of FIG. 19 are designated by the same reference numerals. The series circuit of the inductors 54a and 54b is connected across the input terminal 52 and output terminal 53b, and the capacitor 55 is connected between the point of connection of the inductors 54a and 54b
 30 and the ground.

Here, the circuit of FIG. 20(b) can be considered as a low-pass filter circuit composed of the two inductors 54a and 54b and the capacitor 55. Accordingly, the high frequency signal input to the input terminal 52 undergoes a phase lag through the low-pass filter circuit, and is output from the output terminal 53. In this case, setting its circuit constants appropriately enables the low-pass filter circuit to establish matching, resulting in a low reflection loss. In addition, a desired phase lag can be achieved.

10 【0041】

As described above, the phase-shifting circuit of the embodiment 5 can vary the pass phase involved in outputting the high frequency signal input to the input terminal 52 from the output terminal 53 because the through state and the low-pass filtering state is switched by the switching operation of the through/open switching element 33 and that of the through/shunt capacitance switching element 34. In addition, the present embodiment 5 can further reduce the loss as compared with the cases such as the conventional examples and the embodiments 1-4 that employ the semiconductor switching elements. This is because the present embodiment 5 uses as the switching elements the through/open switching element and through/shunt capacitance switching element which are fabricated through the micromachining technology and are driven mechanically.

25 Furthermore, since the present embodiment 5 employs the hollow structure based on the micromachining technology, the high-frequency characteristic is little affected by the substrate. Thus, it is possible to employ a low-cost substrate such as a low resistance silicon substrate and glass substrate, and hence

30 to reduce the cost as compared with the case of using a

semiconductor substrate.

【0042】

Although the phase-shifting circuit described in connection with FIG. 12 employs as the inductors the hollow structure meander lines of the cavity formed by the single-
5 side micromachining of the substrate, spiral inductors can also be used which are formed by patterning the two sides of the dielectric supporting film. In addition, meander lines with a structure other than the hollow structure can be formed on the
10 substrate. Furthermore, although the foregoing phase-shifting circuit has the high frequency signal transmission lines formed on the dielectric supporting films in the through/open switching element and through/shunt capacitance switching element, another dielectric supporting film can be formed on the high
15 frequency signal transmission lines to make a three-layer structure. This structure, in which the metal patterns are sandwiched between the dielectric supporting films, can make the stress symmetrical in the vertical direction, and hence make it flat. Moreover, it is also possible to form a package by
20 preparing another substrate having a cavity formed by the single-side micromachining, and covering the phase-shifting circuit from the top. This enables the mechanically driven through/open switching element and through/shunt capacitance switching element to be sealed to be protected from moisture
25 and the like, thereby being able to increase the reliability.

【0043】

EMBODIMENT 6

The configuration of the phase-shifting circuit of the
30 present embodiment 6 is obtained by replacing in the phase-

shifting circuit of the foregoing embodiment 5 of FIG. 12 the through/open switching element 33 by a through/open switching element of FIG. 21 which will be described later, and the through/shunt capacitance switching element 34 by a through/shunt capacitance switching element of FIG. 24 which will be described later. The phase-shifting circuit has the same equivalent circuit as the circuit shown in FIG. 19. In addition, since the circuit operation is described in the foregoing embodiment 5, its description will be omitted here.

10 **【0044】**

FIG. 21 is a plan view showing a detailed structure of the through/open switching element used for the phase-shifting circuit of the embodiment 6 in accordance with the present invention. In FIG. 21, the same or like portions to those of FIG. 13 are designated by the same reference numerals, and duplicate explanation will be omitted basically.

At the center of the undersurface of the cavity 39, which is formed by digging down into the single-side of the substrate 38 using the micromachining technology, a pair of beltlike high frequency signal transmission lines 56a and 56b are formed at a distance from each other. In addition, on the undersurface of the cavity 39, ground metals 57a and 57b are formed on both sides of the pair of high frequency signal transmission lines 56a and 56b. Thus, coplanar lines having the gap are formed at the center of the undersurface of the cavity 39.

25 **【0045】**

A dielectric supporting film 58 is supported by the substrate 38 at the edges of the cavity 39 in such a manner as to be normally placed over the hollow of the cavity 39 via an air layer. Thus, the dielectric supporting film 58 is separated

30

from the undersurface of the cavity 39 by a spacing from several microns to several tens of microns, and faces to part of the pair of high frequency signal transmission lines 56a and 56b including the gap (see FIG. 22 which will be described later).

5 On the underside of the dielectric supporting film 58, a contact metal 60 is formed at a location facing to the part of the pair of high frequency signal transmission lines 56a and 56b including the gap. In addition, on the top surface of the dielectric supporting film 58, a control electrode 59 is formed at the
10 location facing to the ground metals 57a and 57b.

【0046】

Next, the operation of the through/open switching element shown in FIG. 21 will be described.

When no voltage is applied to the control electrode 59,
15 a structure of the through/open switching element corresponding to the section taken along the line C-C' of FIG. 21 has a sectional view as shown in FIG. 22. The dielectric supporting film 58 is placed over the hollow of the cavity 39 via the air layer. In this operation mode, the gap between the pair of high frequency
20 signal transmission lines 56a and 56b causes the through/open switching element to form an open state.

On the other hand, when a voltage is applied to the third control electrode 59, the structure of the through/open switching element corresponding to the section taken along the
25 line C-C' of FIG. 21 has the sectional view as shown in FIG. 23. The electrostatic attraction is exerted between the ground metals 57a and 57b (which are invisible in FIG. 23 because 57a is concealed by 56a and 56b, and 57b is placed on this side) and the control electrode 59 so that the dielectric supporting
30 film 58 undergoes displacement toward the undersurface of the

cavity 39. In this operation mode, the pair of high frequency signal transmission lines 56a and 56b make contact with the contact metal 60, and are brought into conduction. Accordingly, the through/open switching element forms a through state.

5 **【0047】**

FIG. 24 is a plan view showing a detailed structure of the through/shunt capacitance switching element used for the phase-shifting circuit of the embodiment 6 in accordance with the present invention. In FIG. 24, the same or like portions
10 to those of FIG. 21 are designated by the same reference numerals.

At the center of the undersurface of the cavity 39, which is formed by digging down into the single-side of the substrate 38 using the micromachining technology, a beltlike high frequency signal transmission line 61 is formed. In addition,
15 on the undersurface of the cavity 39, ground metals 62a and 62b are formed on both sides of the high frequency signal transmission line 61. They form coplanar lines on the undersurface of the cavity 39.

【0048】

20 A dielectric supporting film 63 is supported at the edges of the cavity in such a manner as to face to part of the high frequency signal transmission line 61 and ground metals 62a and 62b. The dielectric supporting film 63 is normally placed over the hollow of the cavity via the air layer (see FIG. 25 which
25 will be described later). Thus, the dielectric supporting film 63 is separated from the undersurface of the cavity 39 by a spacing from several microns to several tens of microns. On the top surface of the dielectric supporting film 63, a control electrode 65 to which the control voltage is applied is formed
30 at a location facing to the ground metals 62a and 62b. In addition,

on the top surface of the dielectric supporting film 63, a metal 64 is formed at a location facing to the high frequency signal transmission line 61. The metal 64 is connected to the ground metals 62a and 62b on the substrate 38 so that it becomes
5 equipotential to the ground.

【0049】

Next, the operation of the through/shunt capacitance switching element as shown in FIG. 24 will be described.

When no voltage is applied to the control electrode 65,
10 a structure of the through/shunt capacitance switching element corresponding to the section taken along the line D-D' of FIG. 24 has a sectional view as shown in FIG. 25. In this operation mode, a sufficient space is present between the dielectric supporting film 63 and the high frequency signal transmission
15 line 61 because of the cavity 39. Accordingly, the high frequency signal is transmitted through the coplanar lines on the undersurface of the cavity 39. Thus, the through/shunt capacitance switching element forms a through state.

On the other hand, when the voltage is applied to the control
20 electrode 65, a structure of the through/shunt capacitance switching element corresponding to the section taken along the line D-D' of FIG. 24 has a sectional view as shown in FIG. 26. In this operation mode, the electrostatic attraction is exerted between the ground metals 62a and 62b and the fourth control
25 electrode 65 so that the dielectric supporting film 63 undergoes displacement toward the undersurface of the cavity 39, and makes contact with the high frequency signal transmission line 61. Accordingly, the metal 64 approaches the high frequency signal transmission line 61 via the dielectric supporting film 63. Thus,
30 the through/shunt capacitance switching element enters into a

state in which it has a capacitance against the ground.

【0050】

As described above, the phase-shifting circuit of the embodiment 6 forms the through state and the low-pass filtering state by the switching operation of the through/open switching element and that of the through/shunt capacitance switching element. Accordingly, as the foregoing embodiment 5, the present embodiment 6 can vary the pass phase caused when the high frequency signal input through the input terminal is output through the output terminal. In addition, since the present embodiment 6 employs the mechanically driven through/open switching element and through/shunt capacitance switching element which are produced by micromachining technology as switching elements, it can further reduce the loss as compared with the embodiments 1-4 which employ the semiconductor switching elements. Furthermore, since the present embodiment 6 employs the hollow structure, the high-frequency characteristic is little affected by the substrate. Thus, it can employ a low-cost substrate such as a low resistance silicon substrate and glass substrate, and hence reduce the cost as compared with the case of using a semiconductor substrate.

【0051】

Although the phase-shifting circuit of the embodiment 6 employs as the inductors the hollow structure meander lines of the cavity formed by the single-side micromachining of the substrate, spiral inductors can also be used which are formed by patterning the two sides of the dielectric supporting film. In addition, meander lines with a structure other than the hollow structure can be formed on the substrate. Furthermore, although the foregoing phase-shifting circuit has the metal patterns

formed on the dielectric supporting films in the through/open switching element and through/shunt capacitance switching element, another dielectric supporting film can be formed to make a three-layer structure. This structure, in which the metal patterns are sandwiched between the dielectric supporting films, can make the stress symmetrical in the vertical direction, and hence make it flat. Moreover, it is also possible to form a package by preparing another substrate having a cavity formed by the single-side micromachining, and covering the phase-shifting circuit from the top. This enables the mechanically driven through/open switching element and through/shunt capacitance switching element to be sealed to be protected from moisture and the like, thereby being able to increase the reliability.

【0052】

EMBODIMENT 7

FIG. 27 is a block diagram showing a configuration of a multibit phase shifter of an embodiment 7 in accordance with the present invention. The multibit phase shifter has a plurality of 1-bit phase-shifting circuits 681, 682, ..., 68n connected in a multistage fashion between a high frequency signal input terminal 66 and a high frequency signal output terminal 67. As the phase-shifting circuits 681, 682, ..., 68n, one of the phase-shifting circuits described in the embodiment 1 to embodiment 6 is used.

Constructing the multibit phase shifter by connecting the 1-bit phase-shifting circuits in a multistage fashion offers an advantage of being able to implement a phase shifter capable of multibit operation.

INDUSTRIAL APPLICABILITY

【0053】

As described above, the phase-shifting circuit in
5 accordance with the present invention can reduce its size with
keeping the low loss characteristic. Therefore it is suitable
for a multibit phase shifter at a high frequency band such as
K-band used by phased-array antennas of a mobile satellite
communication system.